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OF A HINGELESS ROTOR COMPOUND HELICOPTER

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FLIGHT INVESTIGATION OF THE WING-ROTOR LIFT-SHARING CHARACTERISTICS OF A HINGELESS ROTOR COMPOUND HELICOPTER

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Summary

The results of an NASA flight-test program utilizing the Army/Lockheed hingeless rotor compound aircraft to determine the lift-sharing characteristics of the wing and rotor in both level and maneuvering flight are presented. The data show that there is an inherent reduction in rotor lift as level flight airspeed is increased. This reduction in rotor lift provides a margin between the trim lift in level flight and the maximum lifting capability of the rotor which may be utilized in maneuvers. In addition, the measured reduction in rotor-lift sensitivity in accelerated flight which occurs with increasing speed helps to alleviate the rotor stall problems. Although the load-sharing trends contribute favorably to the piloting task in the compound mode, the rotor overspeed tendencies could require constant attention during maneuvering flight.

Introduction

In recent years, several helicopters have been modified to incorporate various degrees of compounding (i.e., auxiliary propulsion and/or wings) in order to verify the expected improvements in high-speed performance and to explore the problems associated with high-speed rotary-winged aircraft. These interim compound aircraft were modified and tested under contracts by the U.S. Army. As one phase of the Army contract, 2 weeks were allotted to NASA Langley Research Center for a flight-test program utilizing the Army/Lockheed hingeless rotor compound helicopter.

This paper presents some of the results obtained during the NASA tests. In particular, the lift-sharing characteristics between the wing and rotor in both level flight and maneuvers are presented and discussed. In addition, data are presented to illustrate the rotor speed control characteristics of the aircraft in maneuvers and autorotations. The results presented herein are related to the flying qualities of this compound helicopter, and the advantages and disadvantages of some of the trends established are pointed out.

Symbols

B_1	longitudinal cyclic pitch angle, deg
GW	aircraft gross weight, lb
L_R	rotor lift, lb

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n	aircraft load factor
rpm	rotor rotational speed expressed as a percent of designed operating speed (355 rev/min)
V	true airspeed, knots
α	boom indicated angle of attack, deg
Δ	incremental change from level flight trim value
θ_0	blade root collective pitch angle, deg

Description of Test Aircraft

The test aircraft, shown in figure 1, is the Army/Lockheed XH-51A compound helicopter which incorporates a hingeless rotor system. The aircraft is described in detail in reference 1. The basic physical characteristics of the aircraft are presented in the following table:

PHYSICAL CHARACTERISTICS OF TEST AIRCRAFT

Nominal take-off weight	5,160 lb
Fuel capacity	695 lb
Rotor diameter	35 ft
Solidity	0.0818
Normal rotor operating speed	355 rpm
Wing span	16.83 ft
Wing area	70 ft ²
Primary powerplant	Turboshaft
Auxiliary powerplant	Turbojet

The pilot's controls are basic helicopter-type controls, and there are no movable aerodynamic control surfaces incorporated. The aircraft is equipped with the standard XH-51A control gyro. The auxiliary power system, of course, requires an additional control which is incorporated into the twist grip of the collective pitch handle. Because of this modification, the primary power control is installed as a throttle on a quadrant mounted to the left of the collective pitch lever.

Results and Discussion

The data presented herein represent a sampling of the data accumulated during the NASA flight-test program. Included are the level flight lift sharing between the wing and rotor, the dynamic or maneuver lift sharing, and also data indicating the rotor rpm control characteristics during maneuvering flight.

The majority of the test results are presented for a nominal collective pitch setting of approximately 4° . This value is the recommended minimum pitch setting for the compound mode of flight for the aircraft.

Level Flight Lift Sharing

The variation of the rotor-lift—gross-weight ratio with airspeed for two collective pitch settings is presented in figure 2. For the 4° collective pitch setting, the rotor lift is equivalent to 57 percent of the gross weight at 110 knots and decreases almost linearly with increasing airspeed. Extrapolation indicates that the rotor would be completely unloaded at approximately 240 knots. Increasing collective pitch, of course, increases the relative rotor loading; however, the maximum airspeed at the higher collective pitch is restricted by an early onset of vibrational problems. The 4° setting provides the maximum range of airspeed wherein the aircraft could be flown without need for a collective pitch change. In addition to minimizing the pilot workload, the trend of decreasing rotor lift as airspeed increases is also advantageous from another standpoint. As the rotor penetrates a more unfavorable environment at the higher speeds, it gradually unloads without pilot action and thus tends to eliminate problems associated with rotor stall.

There are restrictions at both ends of the airspeed range. First, as illustrated in figure 2, the rotor would be completely unloaded at about 240 knots and would probably produce negative lift above this airspeed, with obvious performance penalties. Secondly, with the low collective pitch setting, the aircraft attitude increases rapidly as the airspeed is reduced toward 100 knots. For example, the variation of the level flight fuselage angle of attack with airspeed is presented in figure 3. These data are for the same collective pitch settings as shown in figure 2. The lower collective pitch requires an excessive nose-high attitude in order to achieve the required lift on both the wing and rotor. Thus, flight at airspeeds near 100 knots requires a higher collective pitch setting in order to maintain a more comfortable aircraft attitude.

Lift Sharing in Maneuvers

Of particular importance with regard to flight in the compound mode is the relative load sharing between the wing and rotor during maneuvers. Windup turns were executed in order to establish the rotor-lift variation with load factor for several airspeeds. Sample results are presented in figure 4 to illustrate the trends established for the test aircraft. The data presented were taken at a collective setting of approximately 4° . The variation in rotor lift with airspeed at 1.0g merely reflects the level flight lift variation indicated previously. The data indicate that the rotor is providing a smaller increment of lift for a given load factor

at the higher airspeeds. In order to establish more clearly the trend illustrated, the slopes of the rotor loading with load factor $\left(\frac{d(L_R/GW)}{dn}\right)$ were determined and are plotted as a function of airspeed in figure 5. The curve illustrates the effective decrease in rotor-lift sensitivity with increasing airspeed. For example, in a maneuver the rotor provides approximately 75 percent of the incremental lift at 120 knots, but only 44 percent of the incremental lift at 210 knots. The reduction with speed is very beneficial since less lift demands are made on the rotor during maneuvers as it penetrates the more unfavorable environment at higher speeds.

The decreasing rotor-lift sensitivity with airspeed is in contrast to the trends established for other experimental compounds where the rotor provides a progressively larger share of the lift increment as is indicated by the upper curve in figure 5. It is this high rotor-lift sensitivity which has required control modifications to desensitize the rotor during accelerated flight. Reference 2, for example, presents some results of efforts to control the maneuver lift sharing by collective feedback. It was indicated that cyclic control feedback would also provide a means for controlling the relative loading between the wing and rotor.

An analysis of the data obtained during the tests indicates that there is considerable cyclic pitch feedback occurring during maneuvers which is apparently produced by the mechanical control gyro. Further, it appears that the feedback ratio increases as airspeed increases. For example, figure 6 illustrates the variation of the longitudinal cyclic pitch increment (ΔB_1) with load factor for several airspeeds. The increment ΔB_1 is the difference between the level flight trim longitudinal cyclic pitch and the maneuvering steady-state value. It is actually a combination of the pilot input and the control gyro feedback. It should be noted that in all cases an aft stick displacement was required to maintain a given load factor; however, the steady-state longitudinal cyclic pitch was documented to be in the opposite direction at the higher speeds. In other words, the feedback is large enough at high speeds to wash out the pilot's aft cyclic input (i.e., a negative B_1 increment) and actually produce a positive cyclic pitch increment. Thus, as speed increases, the effective rotor angle-of-attack change in maneuvers becomes progressively smaller. This characteristic, in turn, reduces the rotor-lift sensitivity in maneuvers as speed is increased (see fig. 5).

While the trend of decreasing rotor-lift sensitivity with increasing airspeed is advantageous with regard to avoidance of rotor stall problems, it should be emphasized that the sensitivity change is obtained at the expense of a reduced nosedown longitudinal cyclic control capability. Although not encountered during the program, there are combinations of airspeed and load factor that would utilize the maximum

available nosedown cyclic pitch. Once this condition is reached, the aircraft would be unstable with further increase in angle of attack.

Rotor Speed Control

Rotor speed control is important in terms of both the autorotational and maneuvering rotor overspeed characteristics. Since both of these characteristics are a function of the load factor required to autorotate the rotor, criteria which define these load factors are adequate for establishing the maneuver overspeed restrictions as well as the autorotational requirements. Tests were accomplished to establish the rotor rpm variation with load factor for the aircraft with a fixed collective pitch of 4° . Sample results are presented in figure 7.

The boundary lines indicate the combinations of rpm and load factor that will cause the rotor to autorotate for two different speeds, and the dashed lines represent the desired operating rpm range. The area to the left of each boundary and between the dashed lines represents the envelope wherein shaft power must be supplied to drive the rotor.

From the standpoint of maintaining rotor rpm in the event of primary engine failure, the criteria represent the load factor necessary to prevent an underspeed condition, assuming no other corrective action. For example, at 120 knots the rotor will maintain 100-percent rpm with a load factor of approximately 1.25g. At 170 knots the load factor required to maintain 100-percent rpm has increased to 1.6g.

In terms of rotor overspeed, the same data may be interpreted as the maneuver restrictions for the aircraft in powered flight. If at a constant airspeed the load factor is increased beyond that required to autorotate the rotor, the rpm will increase from the initial setting. Figure 8 illustrates the rpm variation with load factor for two different initial rotor speeds at 120 knots. In both cases the rotor rpm remains fairly constant as load factor is initially increased. However, if the load factor is increased beyond that required to autorotate the rotor, the rotor rpm increases along the boundary as indicated. For the case shown, a steady load factor of 1.45g would result in a final rotor rpm of 110 percent, regardless of the initial rpm.

At higher speeds, the maneuver envelope expands as indicated by the autorotative boundary for 170 knots in figure 7. It is possible to achieve a load factor of 1.6g at 170 knots without exceeding 100-percent rpm. If the airspeed decays during a maneuver while maintaining a constant load factor, the rotor speed would increase to achieve a new equilibrium condition.

The range of airspeeds and load factors presented are in regions where a high percentage of operation is likely to occur, and this could represent maneuvering restrictions of a compound helicopter. The overspeed tendencies would require the pilot to monitor rotor rpm to prevent rotor overspeed during maneuvering flight unless provisions are made to absorb the excess energy.

Concluding Remarks

The flight-test results presented and discussed herein have indicated several trends which are of interest concerning both the performance and flying qualities of a compound helicopter. Specifically, the reduction in rotor lift as level flight airspeed is increased is desirable since no pilot action is required, and the reduced trim lift tends to provide a margin between the trim lift and the lifting capability of the rotor which may be utilized in maneuvers.

In addition, a reduction in rotor lift sensitivity in accelerated flight which occurs with increasing speed also helps to alleviate the rotor stall problem as it penetrates a more unfavorable environment at high speeds. It should be noted, however, that the reduced lift sensitivity occurs at the expense of reduced forward longitudinal control capability.

While these load-sharing trends contribute favorably to the piloting task in the compound mode, the rotor overspeed tendencies would require pilot attention during maneuvering flight.

References

1. Wyrick, Donald R., Extension of the High-Speed Flight Envelope of the XH-51A Compound Helicopter, USAAVLABS Technical Report 65-71.
2. Blackburn, W. E., Methods for Improving Flying Qualities of Compound Aircraft, Journal of the American Helicopter Society, Vol. 13, No. 1, January 1968.

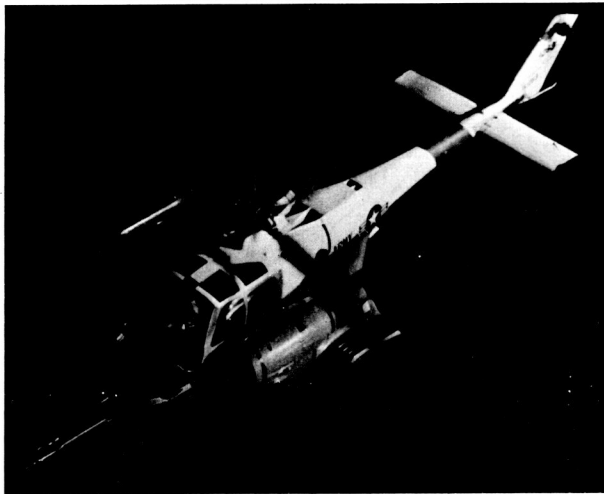


Figure 1.- Test aircraft.

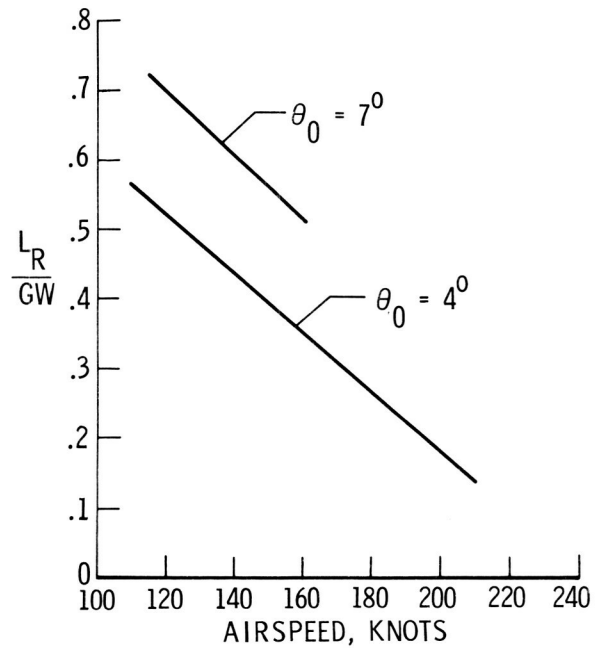


Figure 2.- Rotor lift variation in level flight.

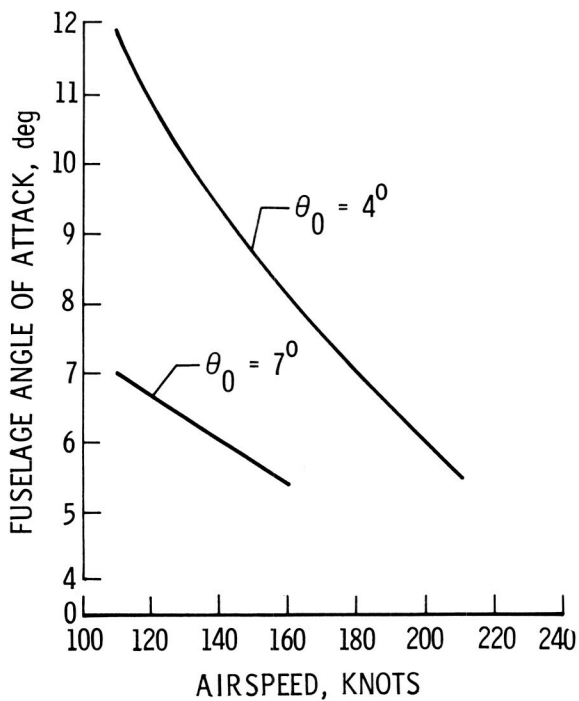


Figure 3.- Angle-of-attack variation in level flight.

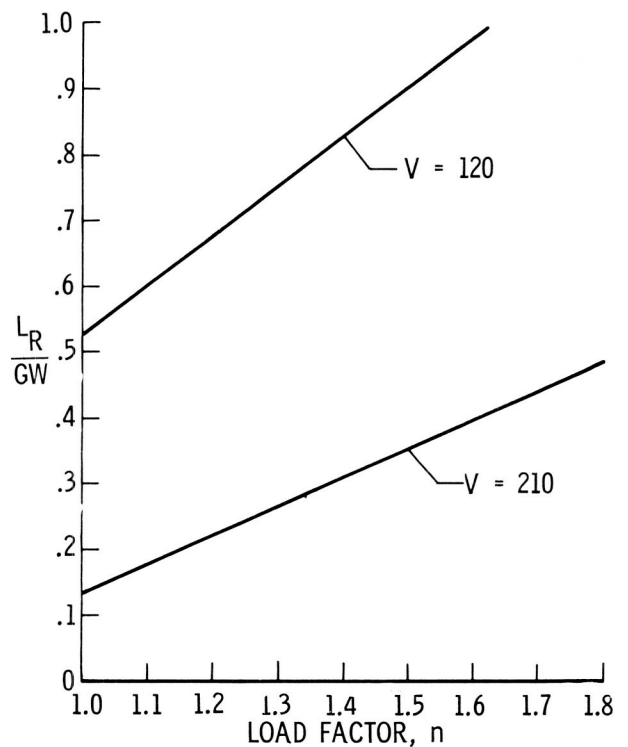


Figure 4.- Rotor lift variation in maneuvering flight.

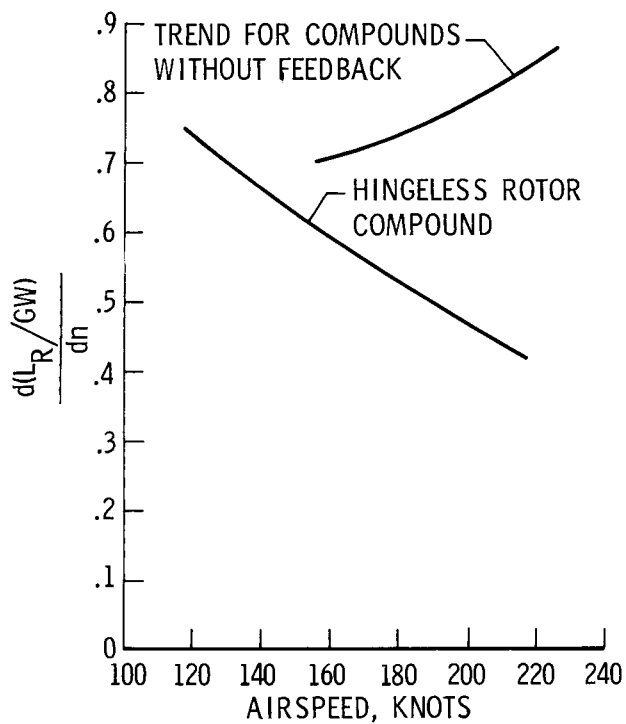


Figure 5.- Effect of airspeed on rotor loading in maneuvers.

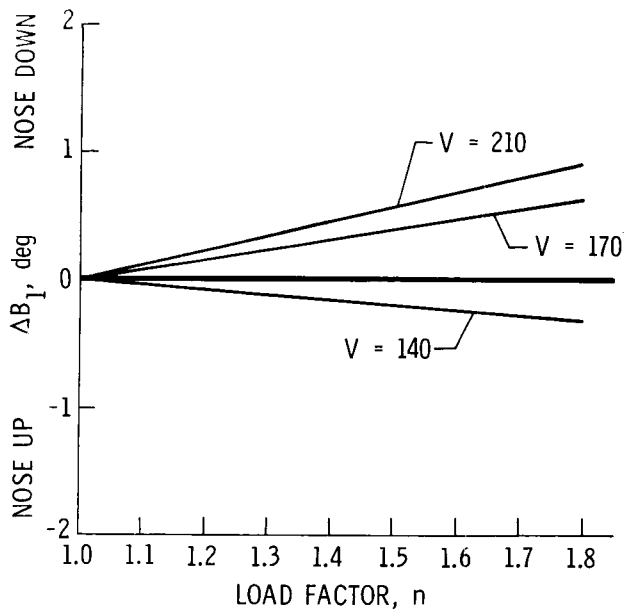


Figure 6.- Longitudinal cyclic pitch increment variation with load factor.

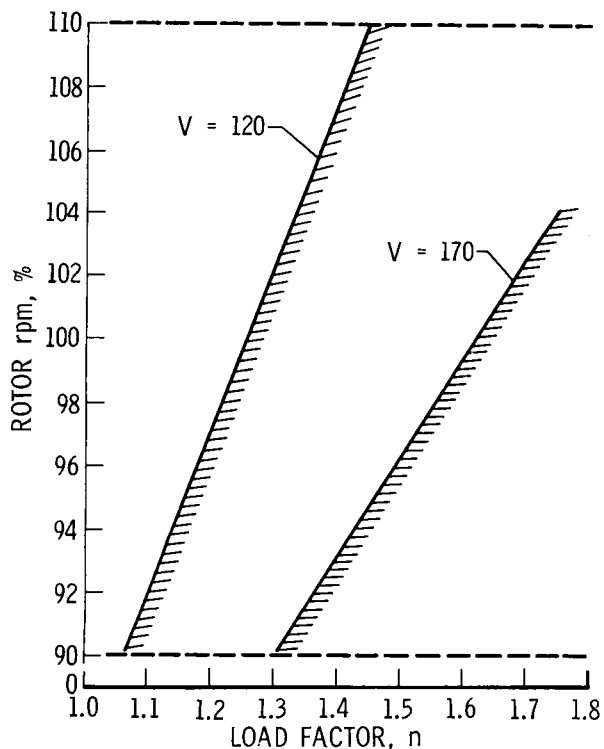


Figure 7.- Power off variation of rotor rpm with load factor.

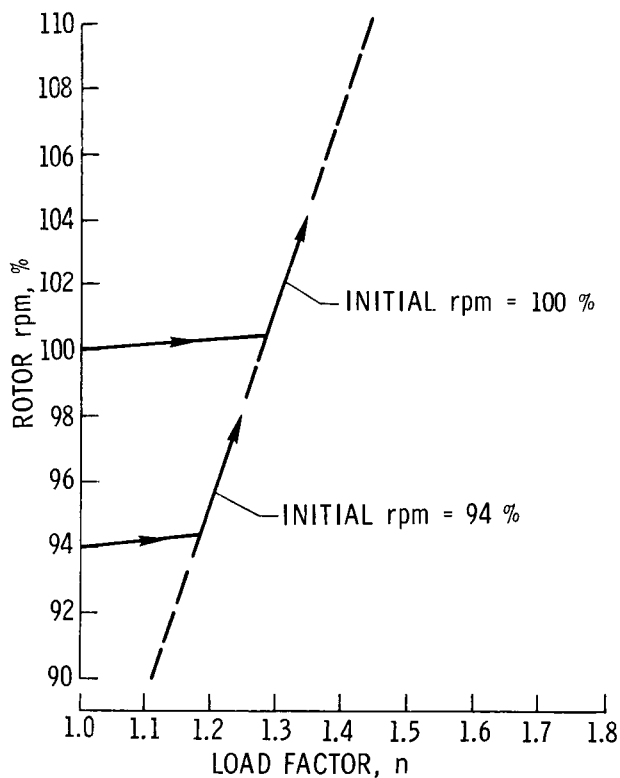


Figure 8.- Variation of rotor rpm with load factor. $V = 120$ knots.